A COMPARATIVE STUDY OF THE DIFFERENT METHODS OF HEAT-RUN TESTS ON ELECTRICAL MACHINES II. THREE-PHASE TRANSFORMERS

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ABSTRACT. The paper makes a critical study of the different methods of heat-run tests on a three-phase transformer and of estimating its final temperature-rise when fully loaded. The results of tests show definitely that the secondary open-vee injection run may be used where it is not possible to carry out the direct loading method.

INTRODUCTION

In a previous communication (Basu, 1950) it was reported that in the absence of facilities for carrying out a direct load test for determining the temperature-rise in a single-phase transformer one may employ the alternate open-circuit and short-circuit heat-run test for the purpose with a fair degree of accuracy. It was further noted that where the final temperature rise takes a considerable time to attain its steady value, one may estimate it with fair accuracy with the Cotton's graphical method. In the present paper are reported the results obtained from tests on a three-phase transformer.

EXPERIMENTAL

In addition to the direct loading method, the following alternative methods have been suggested by several workers (Madden, 1913 ; Stigant and Lacey, 1941) for carrying out a heat-run test on a three-phase transformer without actually loading it :

(*a*) Secondary open-vee injection run,

(*b*) Equivalent short-circuit run,

(*c*) Equivalent open-circuit run, and

(*d*) Alternate open and short-circuit run.

With a view to comparing the results obtained by these different methods with those of the direct loading method, a fairly small three-phase transformer provided with three windings and having the following specifications was chosen :

Type	...	...	...	AN-core type
Output	...	...	...	2 KVA.
Frequency		...	...	50 c/s.

It may be noted here that the innermost winding is rated at 133 volts per coil while the outermost one at 400 volts per coil and the intermediary one at 230 volts per coil.

The measuring instruments and the mercury-in-glass thermometers were all calibrated and checked from time to time during the investigation in comparison to the standards of the laboratory.

Direct load test : The 133-volt coils were used as primary and connected in delta across a 3-phase, 133-volt and 50 c/s source (figure 1).

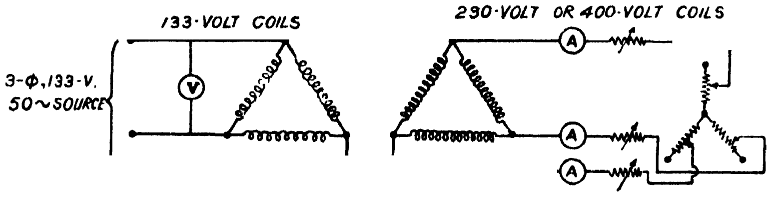

FIG. 1

The primary voltage was maintained constant at the rated value when the transformer was fully loaded on the secondary side. Under the full load conditions the secondary line current was 5 amps. when the 230-volt coils were used as secondary and 2.89 amps. with the 400-volt coils as secondary and was maintained constant throughout the test.

Secondary open-vee test : The connections were made as shown in figure 2.

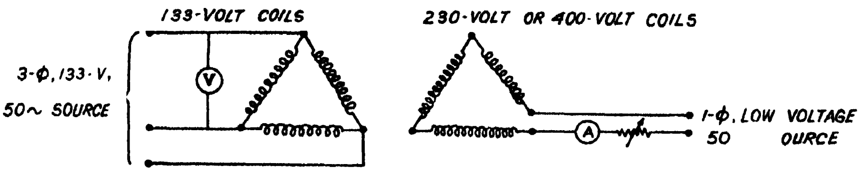

FIG. 2

The primary was connected as in the direct load test. One of the junctions of the delta connection of the secondary was opened and the two points were connected to a 1-phase 50 c/s source of low voltage through an ammeter and a rheostat. The secondary applied voltage was adjusted so as to send the full load phase current through the secondary windings. Since the applied voltage to the primary supplies the core loss and the injected current to the secondary necessary copper loss, the primary applied voltage and the secondary injected current were kept constant at their rated values throughout the test. It is thus evident that the transformer under test although not directly loaded would develop maximum heating because of the presence of the full load losses.

Before carrying out the remaining heat-run tests, the full load losses of the test transformer were determined in the usual way and it was found that the ratio of core loss to copper loss was 3 : 4 when the 230-volt coils were used as secondary and 3 : 5 with the 400-volt coils as secondary.

Equivalent short-circuit test : A low voltage was applied to the primary of the test transformer with its secondary short-circuited and the applied voltage adjusted until the power input (in watts) into the transformer was equal to its normal full load losses. The electrical connections are shown in figure 3.

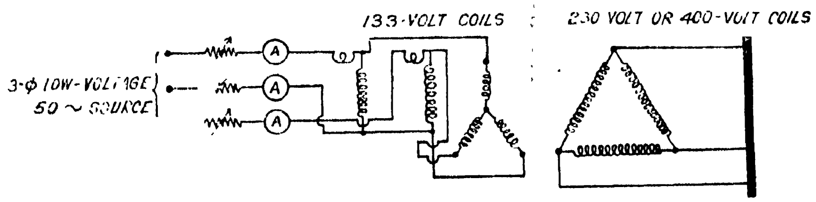

FIG. 3

Equivalent open-circuit test : This test was carried out by applying a high voltage to the primary, keeping the secondary open as shown in figure 4 and

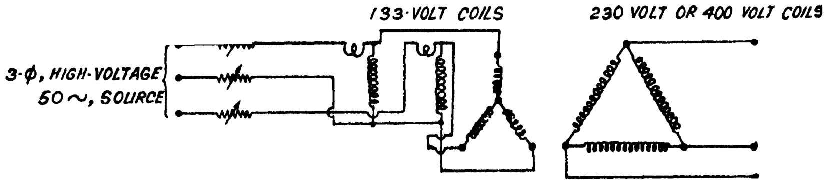

FIG. 4

adjusting the applied primary voltage until the input power (in) watts was equal to the total normal full load losses.

Alternate open-circuit and short-circuit test : For carrying out this test the transformer was connected as shown in figure 5. To begin with, a suitable

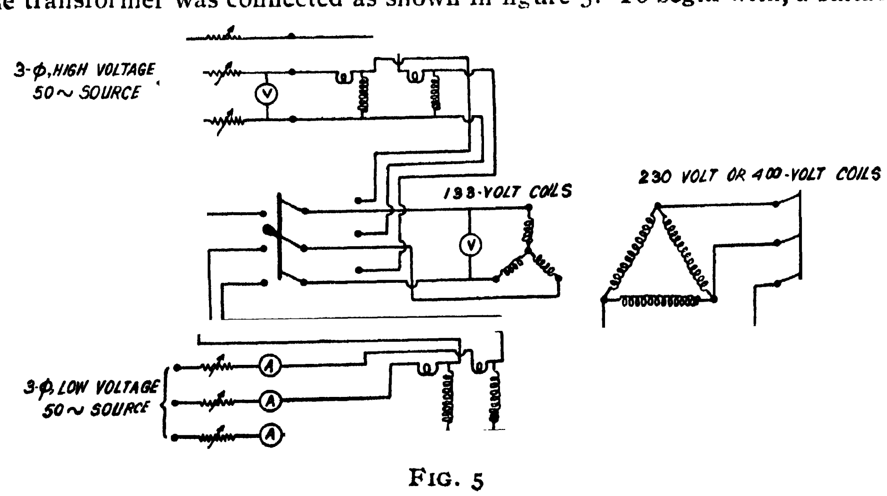

FIG. 5

voltage higher than the rated value was applied to the primary of the transformer with its secondary open and this voltage was gradually increased till the value of the core loss was equal to that of the total full load losses as previously determined. The transformer was run under this condition for 12 minutes and the primary was switched on to a low voltage source. Then with the secondary short-circuited this applied low voltage was adjusted till the copper loss was equal in value to that of the total full load losses. Under this condition the transformer was run for 16 minutes when the 230-volt coils were used as secondary and for 20 minutes when the other secondary was used. This cycle of operations was repeated till a steady hot temperature of the test transformer was reached. It may be noted here that as suggested by McConahey and Fortescue (1913) and also Madden (1913) the period of each run was so chosen that the ratio of the two periods of the two heat-run tests was equal to that of the core loss and the copper loss of the test transformer.

TABLE I
Direct-loading heat-run test

Time		Temperature in °C			
		230-V. secondary		400-V. secondary	
Hour	Min.	Cold	Hot	Cold	Hot
0	0	30.40	30 40	30.70	30 70
0	15	30.40	32.70	30.75	34.00
0	30	30 40	37 20	30 75	39.90
0	45	30.40	41 30	30.75	44.50
1	0	30.50	44.70	30.75	48.50
1	15	30 50	47 50	30.75	51 70
1	30	30.50	49 80	30.75	54.20
1	45	30.50	51.70	30.85	56 20
2	0	30.50	53 30	30.85	57.90
3	0	30.55	57.35	30.85	62 00
4	0	30 70	59 60	30.95	64 50
5	0	30.70	60.90	31.00	65 70
6	0	30.80	61.80	31.05	66.60
7	0	30 90	62.20	31.05	67.10
8	0	30.90	62 40	31.05	67 30
9	0	30 90	62.40	31 05	67 30

TABLE II

Secondary open-vee injection heat-run test

Time		Temperature in °C			
		230-V. secondary		400-V. secondary	
Hour	Min.	Cold	Hot	Cold	Hot
0	0	30.60	30.60	30.60	30.60
0	15	32.55	32.60	30.50	36.90
0	30	30.50	36.90	30.55	42.35
0	45	30.50	40.60	30.60	46.70
1	0	30.50	43.70	30.60	50.30
1	15	30.50	46.30	30.60	53.10
1	30	30.50	48.50	30.65	55.50
1	45	30.50	50.30	30.65	57.30
2	0	30.50	51.90	30.65	58.90
3	0	30.50	56.00	30.65	62.70
4	0	30.35	58.30	30.70	64.75
5	0	30.35	59.30	30.70	66.20
6	0	30.40	60.25	30.70	67.00
7	0	30.40	60.80	30.70	67.30
8	0	30.40	61.20	30.70	67.30
9	0	30.40	61.20	—	—

TABLE III

Equivalent short-circuit-heat run test

Time		Temperature in °C			
		230-V. secondary		400-V. secondary	
Hour	Min	Cold	Hot	Cold	Hot
0	0	31.70	31.70	30.10	30.10
0	15	31.50	34.80	30.10	40.00
0	30	31.50	41.40	30.10	48.00
0	45	31.50	46.80	29.95	54.00
1	0	31.50	50.90	29.95	58.50
1	15	31.60	54.20	29.90	61.80
1	30	31.60	56.80	30.00	64.20
1	45	31.60	58.90	29.80	66.10
2	0	31.60	60.50	29.80	67.50
3	0	31.60	63.70	30.00	71.30
4	0	31.60	65.50	29.90	72.80
5	0	31.70	66.60	29.90	73.80
6	0	31.70	67.30	29.95	74.30
7	0	31.70	68.00	29.95	74.60
8	0	31.80	68.30	29.95	74.60
9	0	31.80	68.30	—	—

TABLE IV

Equivalent open-circuit heat-run test

Time		Temperature in °C			
		230-V. secondary		400-V. secondary	
Hour	Min.	Cold	Hot	Cold	Hot
0	0	31 40	31.40	30 50	30.50
0	15	31.30	31 70	30.50	30.70
0	30	31.30	32.20	30.50	31 30
0	45	31.30	32 90	30 50	32.20
1	0	31.30	33 70	30,50	33.15
1	15	31.35	34 60	30 50	34 20
1	30	31.35	35.60	·0 50	35.30
1	45	31 35	36 60	30 50	36.40
2	0	31.35	37 50	30.50	37.50
3	0	31 40	40 50	30.50	41 00
4	0	31.40	42.50	30 55	43.40
5	0	31.40	43.80	30.55	44.90
6	0	31 40	44 50	30.55	45.80
7	0	31 40	45.10	30.60	46.50
8	0	31.40	45 30	30.60	46 90
9	0	31.40	45 30	30.60	46 90

TABLE V

Alternate open-circuit and short-circuit heat-run test

230-V. secondary				400-V. secondary			
Time		Temperature in °C		Time		Temperature in °C	
Hour	Min.	Cold	Hot	Hour	Min.	Cold	Hot
0	0	31.30	31.30	0	0	30.50	30 50
0	20	31.30	32.30	0	22	30.50	37.20
0	48	31.20	39.80	0	54	30 50	47.50
1	16	31.20	44.70	1	26	30 50	53 80
1	44	31 20	48.40	1	58	30.45	57.20
2	12	31 20	50 80	2	30	30.45	59.60
2	40	31.05	52 70	3	2	30 60	61.00
3	8	31.00	54.00	3	34	30 50	62 00
3	36	31.00	54 60	4	6	30.60	62 90
4	4	30.90	55.40	4	38	30.60	63 70
4	32	31 00	56.00	5	10	30 65	64.30
5	0	31.00	56 20	5	42	30.65	64.50
5	20	30.90	56 40	6	14	30 65	64.50
5	56	30.00	56.40	—	—	—	—

Temperature measurement : The temperature was measured, as described in the previous communication (Basu, 1950), except that the thermometer was placed in contact with the outermost winding. Since the estimation of temperature-rise by the measurement of hot resistance has no special advantage over the thermometric method, it was thought desirable to estimate the temperature-rise by the graphical methods in addition to the thermometric method. Tables VI and VII contain the data of temperature-rise as estimated by each of these three methods. In each table, the columns 2, 3, and 4 refer to data of temperature rise as indicated below :

Column 2 :—As read by the thermometer placed in contact with the outermost winding.

Column 3 :—As found from the graph $d\theta/dt$ *vs.* θ.

Column 4 :—As found by Cotton's graphical method.

TABLE VI

230-V. secondary

Methods of heat-run tests	Temperature-rise in °C		
1	2	3	4
Direct loading	31.50	30.10	31.00
Secondary open-vee-injection	30.80	30 00	32.00
Equivalent short-circuit	36.50	34 80	37.00
Equivalent open-circuit	13.90	14.40	20.00
Alternate open & short-circuit	25 50	—	33 00

TABLE VII

400-V. secondary

Methods of heat run tests	Temperature-rise in °C		
1	2	3	4
Direct loading	36.25	34.30	34.00
Secondary open-vee injection	36.60	35.40	26.00
Equivalent short-circuit	44.65	41.40	41.00
Equivalent open-circuit	16 30	17.25	25.00
Alternate open & short-circuit	33.85	—	38.00

DISCUSSIONS

From Tables VI and VII one may note the following :

(i) The transformer under test is well within the limit of temperature-rise as stipulated for an AN-type of transformer with class A insulation and running continuously under full load conditions.

(ii) Amongst the alternative methods the results obtained by the secondary open-vec injection heat-run test are in very close agreement with those obtained by direct loading method as can be easily seen from column 2 of each table.

(iii) The two graphical methods give fairly satisfactory results but in view of the uncertainty involved in the Cotton's graphical method, one is led to prefer the first graphical method.

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REFERENCES

Basu, H. K , 1950, *Ind. J. Phy.*, **24**, 171.
Madden, J. J., 1913, *Proc. A. I. E. E.*, **32**, 325.
McConahey, W. M. & Fortescue, C., 1913, *Proc. A I. E. E.*, **32**, 507.
Stigant, S. A , & Lacey, H. M., 1941. The J. & P. Transformer Book.